

OUTDOOR AIR POLLUTION, HEALTH AND HEALTH COSTS IN VIRGINIA

Report for State Advisory Board - Air Pollution

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Introduction, Mission Statement & Scope

The 2006 State Advisory Board – Air Pollution asked SAB member Dudley F. Rochester, M.D., to prepare a report on a) the impacts of outdoor air pollution on human health and health costs, and b) the effects of interventions to lower air pollution.

The mission is to review the relevant medical, epidemiological and economic data in literature related to health effects of outdoor air pollution, to organize and interpret the findings of these articles, and to present the results in a format that emphasizes the impacts of outdoor air pollution on health and health costs in Virginia.

Most of the available articles reviewed for this report focused on ozone and particulate matter. The report summarizes data about direct effects of ozone and/or particulate matter on human health, health and other related costs, and impacts of interventions that lower air pollution levels on health and health costs.

This report does not cover a) economic impacts of ambient air pollution such as damage to farm animals, crops and forests, or loss of tourism business; b) indoor air pollution; and c) mercury, which is the subject of a separate 2006 report by the State Advisory Board – Air Pollution.

Executive Summary

- Outdoor air pollution from ozone and fine particulate matter causes significant morbidity (asthma and other respiratory diseases, heart disease and stroke) and premature mortality (adult and infant). The death rate attributable to air pollution is approximately 45% of that attributable to tobacco, and 8% of overall mortality.
- Direct medical costs in the United States come to approximately \$400 per year per Medicare recipient, and overall health costs are approximately \$800 a year per adult. In Virginia that comes to \$4.8 billion per year, or 1.6 % of Virginia's gross domestic product.
- Interventions that lower the air concentrations of ozone and particulate matter are associated with reductions in respiratory illness and overall death rate. In Virginia, a 33% reduction in current levels of ambient particulate matter and ozone would reduce respiratory illnesses in children by approximately one-third. Premature deaths would fall by 21 per 100,000 of the population per year (approximately 2.5% of the total death rate). Reducing medical costs would save \$1.6 billion per year.

Ozone & Particulate Matter (PM)

Ozone precursors. Volatile organic compounds (VOC) are substances such as paint thinners, gasoline, solvents and many other organic chemicals, from nature as well as from human endeavor, that evaporate into the air. Oxides of nitrogen (NO_x) are produced by burning fossil fuels in electric power plants, other types of factories and in internal combustion engines located on- and off-road. Approximately 45% of VOC and 63% of NO_x come from mobile sources. Ozone is formed in the troposphere, the part of the earth's atmosphere that is close to the ground, through chemical reactions powered by sunlight and involving VOC and NO_x. Ozone can be transported by wind currents to hundreds of miles away from its source. Sulfur dioxide (SO₂) and NO_x are important precursors of PM_{2.5} formed in the atmosphere.

Sources of Particulate Matter. Some fine particles come from disruption of the earth's crust by sandstorms, excavation, volcanic activity and other phenomena. Although the mass of particles of crustal origin is approximately four times that of particles resulting from the combustion of fossil fuel, we inhale many more of the latter because they are finer particles. Fine particles originating from fossil fuel combustion are formed in stationary sources such as power plants and factories, as well as in mobile sources such as internal combustion engines on- and off-road, locomotives, construction equipment, farm and yard equipment, boats, airplanes etc. In addition, fine particles are formed by chemical processes in the atmosphere involving gases emitted by burning fossil fuels.

Classes of Particulates. Particulate matter (PM) exists in multiple classes. The term black smoke (BS) refers to a mixture of sizes, measured optically. Another group is total suspended particulates (TSP). Smaller particulates are referred to by their size, specifically, by their diameter in micrometers (μ). The two principal groups of particulates monitored by US EPA and Virginia DEQ are those with a mean diameter under 10 μ (PM₁₀) and particles with a mean diameter less than 2.5 μ (PM_{2.5}). PM₁₀ and PM_{2.5} are referred to as fine particles. On average, PM_{2.5} particles comprise about 70% of PM₁₀ by mass. However, PM_{2.5} particles are 10 to 100 times more numerous, and owing to their smaller size, they have a higher ratio of surface to volume.

The concentrations of the different types of particulate matter in air tend to vary up and down together. BS concentration is easily determined by absorption of light by particulate matter, and the BS level can be used as an indicator of diesel exhaust emissions (Gotschi 2002).

Particulates Relevant to Health. Most of the reports that deal with health effects of particulate air pollution concern PM₁₀ and PM_{2.5}. These are the particulates that are most harmful to human health, especially those produced in motor vehicles (Laden 2000, Lanki 2006). The technology for measuring PM_{2.5} levels in air was not widely available until the mid-1990s, so some studies report only on TSP, BS and other particulates.

Air Concentration Trends in Virginia

Emissions of PM₁₀, NO_x, sulfate (SO₂) and VOC fell by 10 to 46% from 1990 to 2002. In like fashion, air concentrations of ozone, PM₁₀, NO_x and SO₂ fell by 12 to 39 % from 1993 to 2003. However, between 2004 and 2005 the air concentrations of ozone, PM₁₀ and PM_{2.5} increased by approximately 5 to 12% in Virginia (Table 1). The utilization of electric power is projected to grow until 2050, the population of Virginia increased approximately 33% between 1980 and 2000, and vehicle miles traveled increased 99% during the same period. Recently adopted EPA diesel, gasoline and emissions standards may ameliorate the rise in emissions of PM_{2.5} over coming decades. However, if trends in population, power consumption and vehicle miles traveled continue upward, one can expect that particulate emissions and air concentrations will either continue to grow or at least remain high.

Table 1, based on data supplied by the EPA website for cities and counties in Virginia, shows air concentration data for ozone, PM₁₀ and PM_{2.5} for years 2004 and 2005. The values for PM₁₀ and PM_{2.5} are annual means; and the values for ozone are 8-hour maxima. The EPA standard is 50 micrograms per cubic meter of air (µg/m³) for PM₁₀, 15 µg/m³ for PM_{2.5}, and 80 parts per billion (ppb) for ozone.

Table 1: Average values for ozone, PM ₁₀ and PM _{2.5} in Virginia				
		Year		Percent
Pollutant	Units	2004	2005	Difference
Ozone	ppb	75	79	+5.3
PM ₁₀	µg/m ³	18.8	21.0	+11.7
PM _{2.5}	µg/m ³	13.2	14.1	+6.8

The average values from all monitoring sites in the state for ozone and PM_{2.5} are close to the EPA standards. In the large metropolitan areas of Virginia, the 8-hour ozone standard is often exceeded, and the PM_{2.5} standard is sometimes exceeded.

Assessment of Health Effects

The impact of air pollution on health can be assessed in multiple ways. Questionnaires distributed to patients and/or their families provide information about respiratory symptoms such as wheezing, shortness of breath, tightness in the chest, cough and production of sputum. The function of the lungs can be assessed by various breathing tests. Such data can be recorded over many years to determine if there are long-term decrements in lung function. Events such as the number of asthma attacks, visits for emergency care and hospitalizations can be tabulated. Death rates from asthma, chronic obstructive pulmonary diseases (COPD) and lung cancer can be related to short-and long-term exposure to ozone and fine particulates.

Mechanism of Air Pollution-Induced Illness

Particle deposition in the lungs: Respiratory and other illnesses may be related to the presence of fine particulate material in the lungs. In a study that compared findings in Mexican and Canadian cities, the lungs of women who died of non-respiratory diseases were studied for their particle content. The prevailing level of PM₁₀ in the air was 4.7 times higher in Mexico City than in Vancouver, and the lungs examined in Mexico City contained 7.4 times more particles than lungs from Vancouver. The particles in the lungs had characteristics of diesel exhaust (Brauer 2001).

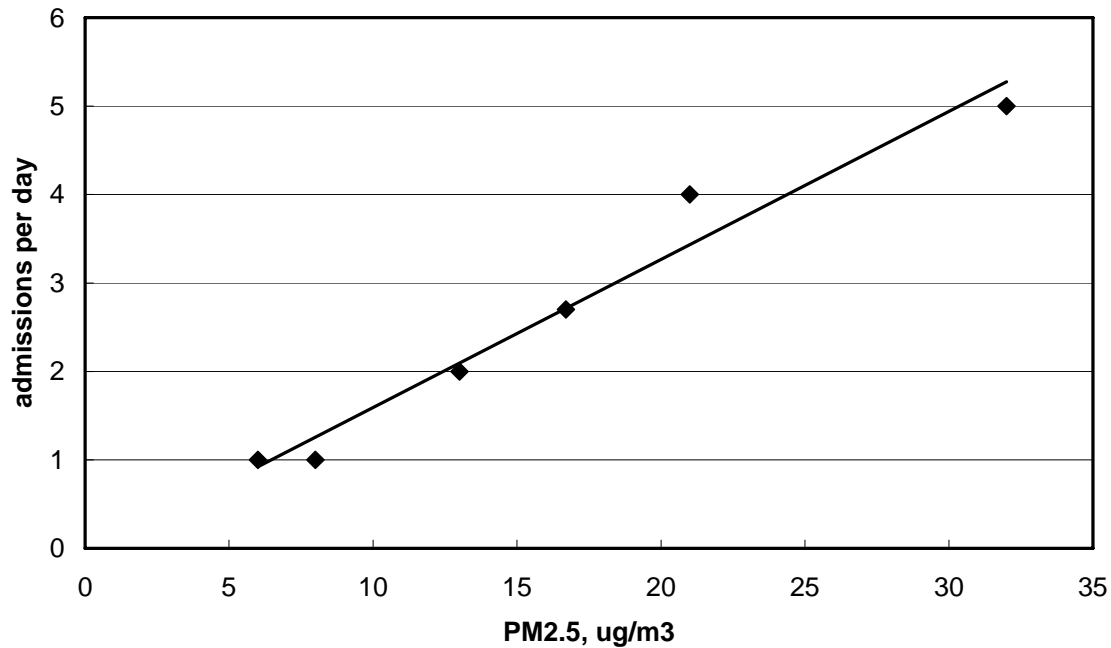
Inflammation. Ozone is a highly reactive substance that reacts with biological compounds to form oxygen free radicals. These radicals are also highly reactive, promoting inflammation and damaging living tissues. Fine particulate matter contains heavy metals and endotoxin which can also initiate inflammation (Ghio 2001, Long 2001, Tolbert 2002, Schaumann 2004). Instillation of fine particles into the lungs of human volunteers evokes an inflammatory response characterized by the appearance of inflammatory cells and substances called cytokines in the lungs (Ghio 2001, Schaumann 2004). Humans who inhaled fine particulate matter developed biochemical markers of inflammation in their blood and urine (Fujii 2001, Ruckeri 2006, Rabinovitch 2006).

The thickness of the inner and middle lining of the human carotid artery, which is related to inflammation in the lining, is proportional to the concentration of PM_{2.5} (Kunzli 2005). Cardiovascular mortality related to air pollution is thought to be mediated by inflammation (Pope 2004).

Respiratory Illness

Morbidity. The prevalence of respiratory illness in children is related to levels of ozone and fine particulate pollution (Romieu 1996, Sheppard 1999, Gent 2003, Rabinovitch 2006). In addition to PM_{2.5} and PM₁₀, TSP, SO₂ and NO_x are also involved (Zhang 2002). Deaths from asthma are related to NO_x and ozone (Sunyer 2002). Figure 1, based on data from Sheppard (1999) illustrates the number of hospitalizations per day in Seattle for asthma as related to the concentration of PM_{2.5}. Hospitalization rates for adults with respiratory diseases are also related to ozone and PM₁₀ (Atkinson 2001, McGowan 2002).

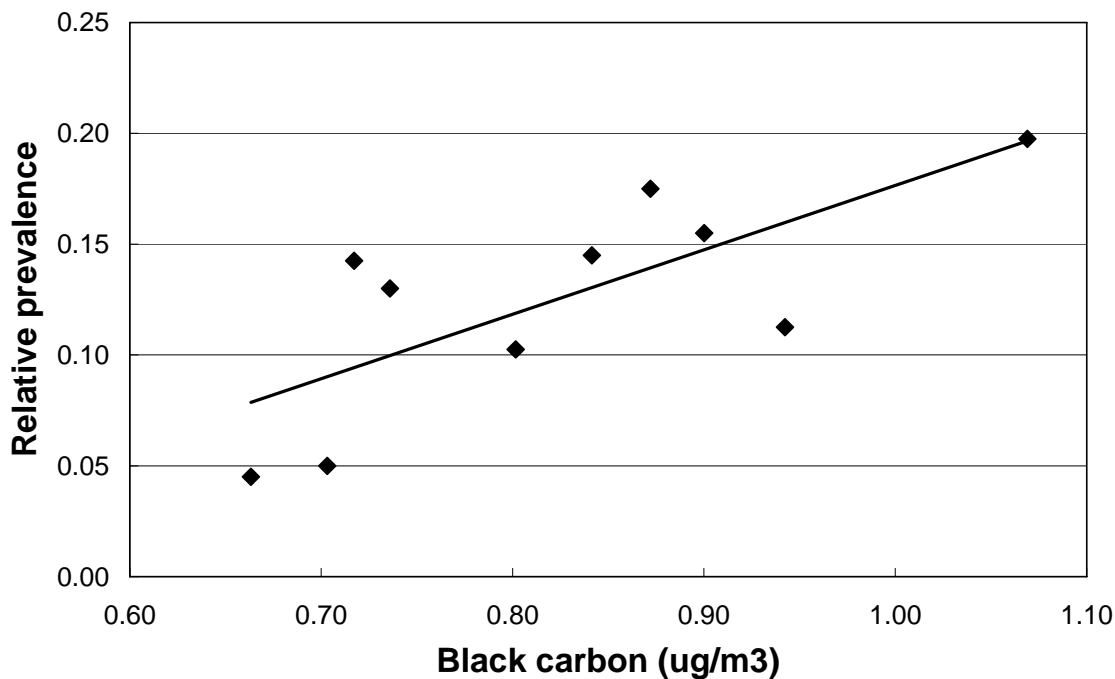
Figure 1. PM2.5 and Hospitalizations for Asthma



Lung function. As children grow, their lungs become larger and the numerical values for tests of lung function also increase. Several studies involving three to eight years of follow-up have shown that deficits in the growth of lung function, as assessed by lung function tests, are related to exposure to ozone, fine particulates, NOx and acid vapor (Gauderman 2002, 2004, Horak 2002).

Influence of traffic. Respiratory illness in children and adults is higher in areas adjacent to high motor vehicle traffic (Hoek 2002, Garshick 2003, Kim 2004, McConnell 2006). Figure 2 (Kim 2004) shows the effect of the concentration of black carbon in the air on the prevalence of bronchitis in school children. Each point on the graph is one school in Southern California. It is clear that the higher the black carbon concentration in the air, the higher is the prevalence of bronchitis (a 40% increase in black carbon doubles the relative prevalence).

Figure 2. Black Carbon & Bronchitis in Schools



Infant Morbidity & Mortality

Low birth weight, a predictor of infant mortality, is associated with maternal exposure to SO₂ and TSP during the third trimester of pregnancy (Wang 1997). Exposure to CO, PM₁₀ and NO_x is associated with increased mortality in infants aged 1-12 months (Ritz 2006). Maternal exposure to ambient air pollution is associated with a variety of fetal abnormalities (Bocksay 2005, Perera 2002). Cardiac defects in fetuses are associated with exposure of mothers to carbon monoxide and ozone in the first trimester of pregnancy (Ritz 2002).

Infant mortality increases with increasing levels of PM₁₀ (Ha 2003). In US metropolitan areas, mortality from all causes, sudden infant death syndrome and childhood respiratory diseases increase in proportion to PM₁₀ concentrations in the air (Kaiser 2004).

Cardiovascular Disease & Stroke

Fine particulate pollution is associated with an increase in the incidence of heart attacks and precipitation of congestive heart failure (Wellenius 2005a, Wellenius 2006, Dominici 2006), and in the incidence of ischemic strokes (Hong 2002a, 2002b, Wellenius 2005b, Low 2006). The number of emergency admissions for heart attack and the risk of death from heart attacks both increase when PM_{2.5} increases (Zanobetti 2005, Dominici 2006). High levels of exposure to PM_{2.5} lead to atherosclerosis, which underlies both ischemic stroke and heart attacks (Kunzli 2005). The probability of having a heart attack is increased by exposure to traffic (Peters 2004).

Adult Mortality

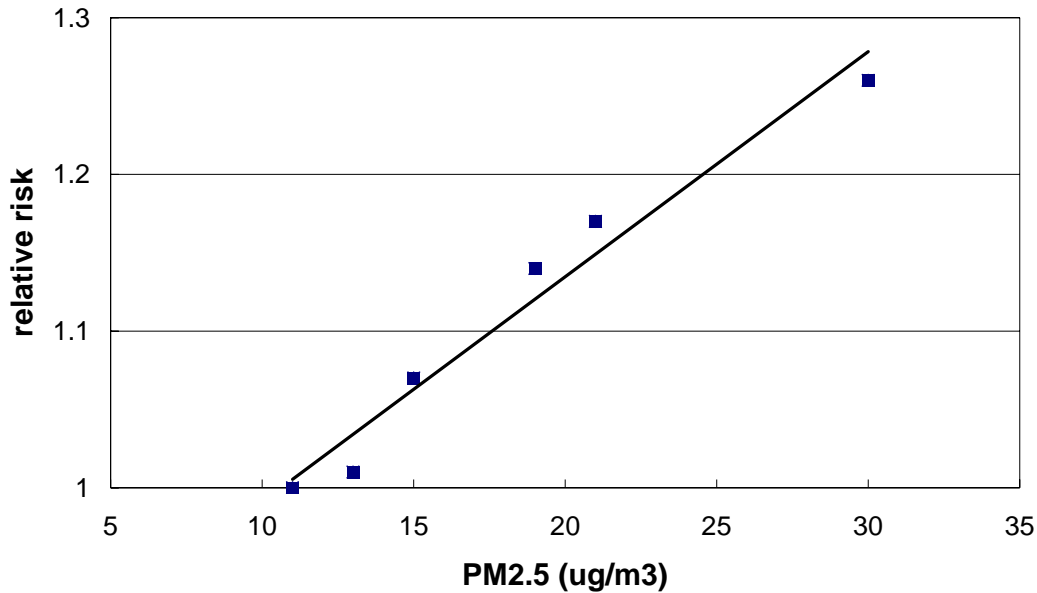
The association between fine particulate air pollution and increased risk of dying from all causes other than trauma has been demonstrated repeatedly (Schwartz and Dockery 1992, Dockery 1993, Pope 1995, Samet 2000, Goldberg 2001a, Goldberg et al. 2001b, Valois 2001, Pope 2002, Ballester 2002, Medina 2004, Jerrett 2005). The relative risk from of an exposure to equal mass concentrations is much higher for PM_{2.5} than from PM₁₀ (Samet 2000, Pope 2002). Exposure to ozone carries a finite risk of mortality unrelated to exposure to particulates (Gryparis 2004, Bell 2005). The risks of dying from COPD, lung cancer and heart disease after exposure to air pollution are substantially higher than the risk for all-cause mortality.

Worldwide, PM_{2.5} causes about 3% of mortality from cardiopulmonary disease, 5% of mortality from cancer of trachea, bronchus and lung, and about 1% of mortality from acute respiratory infections in children under age 5 years. It amounts to 0.8 million premature deaths (1.2 %) and 6.4 million years of life lost (Cohen 2005). Even short-term exposure to particulates increases the mortality rates beyond the effect of hastening the death of the most vulnerable people (Zanobetti 2002, Hoyos 2003).

The data in Figure 3 (see below) are taken from the original six cities study (Dockery 1993). Each point in the graph represents a single city. The six cities are located in the eastern and Midwestern parts of the United States. The mean air concentrations of PM_{2.5} ranged from 11 µg/m³ of air in the least polluted city to 30 µg/m³ in the most polluted.

In the six cities study, the relative risk of dying is highest in the most polluted city. These findings have not been altered by extensive reanalysis and follow-up (Dockery 1993, Laden 2000, Laden 2006). By way of comparison, the relative risk of dying prematurely is 2.3 for a current smoker, 1.5 for a former smoker and 1.3 from PM_{2.5} in a heavily polluted city.

Figure 3: Relative Risk of Dying



The relationship between daily death rate and the concentration of either ozone or PM_{2.5} is linear, i.e. relative risk of dying varies directly with the level of pollutant. Statisticians find no evidence for a threshold, i.e. a little air pollution is bad and more is worse (Goldberg et al., 2001a, Schwartz 2002, Gryparis 2004, Bell 2006). The magnitude of the relationship depends on duration of exposure (Dominici 2003, Goodman 2004).

Table 2 shows the death rates in the United States. The overall death rate in the United States is approximately 830 per 100,000 of the population per year. The death rate from tobacco use is approximately 17% of the US total (US Census Bureau). Air pollution accounts for approximately 8%, with a range of 12 to 146 and a median value of 64 deaths per year per 100,000 of the population (Pope 1995, Samet 2000, Kunzli 2000, Pope 2002, Clancy 2002, Ballester 2002, Medina 2004, Jerrett 2005). Note that the rate for air pollution exceeds the rate for alcohol, firearms and motor vehicle accidents combined.

Table 2: Comparison of Mortality Rates in the United States		
Cause of death	Rate/100,000	Percent
US total	830	100
Tobacco	150	18
Air pollution	64	8
Alcohol, firearms, & motor vehicle accidents combined	57	7

Health Costs of Air Pollution

There is a strong correlation between the concentration of PM₁₀ in the air and utilization of outpatient and inpatient medical services by Medicare recipients in the United States (Fuchs and Franks 2002). These investigators estimated that reducing the concentration of PM₁₀ by 10 µg/m³ would lead to a savings of \$177 per year per senior citizen. Given the currently prevailing level of PM₁₀, the total direct medical cost would be approximately \$370 per Medicare recipient per year.

In southern California, the total cost of school absences related to air pollution was approximately \$245 million (Hall 2003). It was estimated that the reductions in air pollution estimated to occur by 2010 will result in fewer children visiting emergency rooms, fewer hospitalizations, a reduction in number of low birth rate infants, with an annual medical savings of approximately \$267 million for children (Wong 2004).

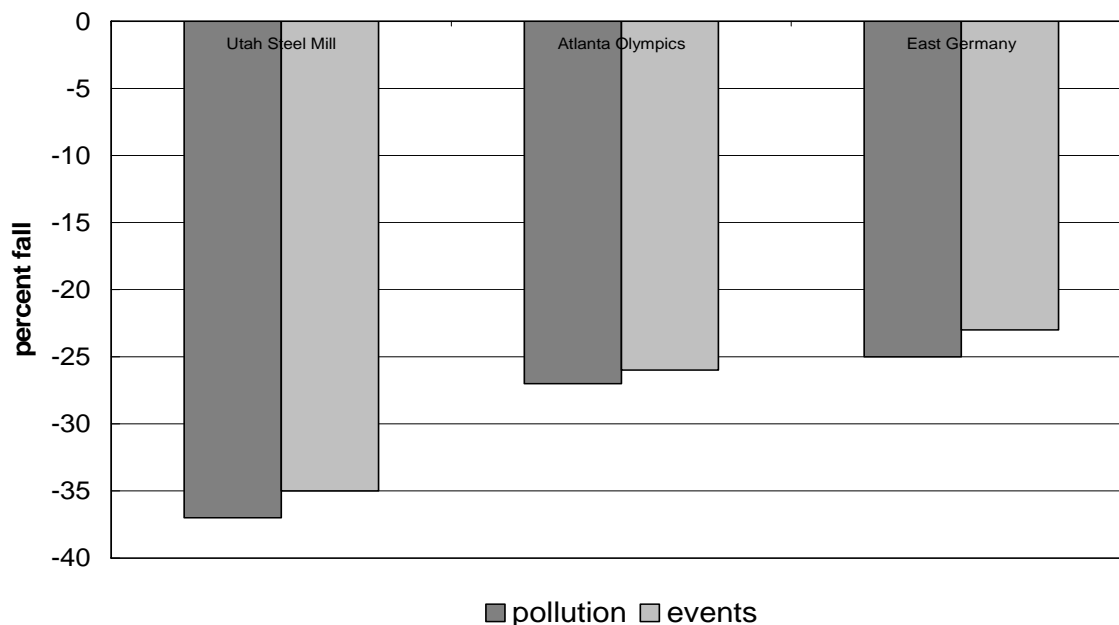
Studies based on large populations indicate that total health costs of air pollution, which include the impact of premature deaths, range from \$600 to \$1,000 per adult per year (Hall 1992, Levy 2001, Kunzli 2002, Hall 2006). The average is approximately \$800 per adult per year. In Virginia that would come to approximately \$4.8 billion per year, or 1.6 % of Virginia's gross domestic product.

Effect of Interventions

Rate of fall. When emissions of air pollutants cease, air pollution levels drop rapidly. In a 2003 power outage that affected mid-Atlantic states there were 50-90% reductions in SO₂, ozone and light scattering particles within 24 hours (Marufu 2004).

Morbidity. In several places local or regional levels of particulate air pollution fell for several weeks or longer. Studies of these events have yielded valuable information on the impact of interventions on pollution-related illnesses. In the Salt Lake City area a steel plant was closed for a year for economic reasons (Pope 1989). In East Germany, particulate pollution fell substantially after reunification (Heinrich 2000). The downtown area of Atlanta was closed to traffic for several weeks during the 1996 summer Olympic Games (Friedman 2001). The results of these studies are depicted in Figure 4 on page 10. Note that for each percent decrement in air pollution (dark grey bars), there is a nearly identical decrement in respiratory illness (light grey bars).

Figure 4. Effect of Interventions



Mortality. In Dublin, Ireland the sale of bituminous coal for home space and water heating was banned in 1990. Mortality ascribable to air pollution was studied for 6 years before and 6 years after the ban. The concentration of black smoke (BS) in the air fell by 70%. Death rates from all causes except trauma fell by 5.7%, respiratory deaths fell by 15.5 % and cardiovascular deaths fell by 10.3%. Approximately 75 deaths per year per 100,000 population could be attributed to air pollution (Clancy 2002).

Consequences of Lowering Air Pollution in Virginia

A one-third reduction in current levels of ambient particulate matter and ozone would be expected to reduce asthma and bronchitis in children by approximately one-third. Premature deaths would fall by 21 per 100,000 of the population per year, or approximately 2.5% of the total death rate. The savings from reduced medical costs would come to approximately \$1.6 billion per year.

Progress to Date

The data presented in the references cited do not take into account measures taken in recent years to ameliorate outdoor air pollution. In the United States, measures have already been in effect for several years to reduce emissions from on-road vehicles and power plants. Internal combustion engines are more efficient. As of October 2006, diesel fuel has 90% less sulfur. In 2007, emissions from selected off-road vehicles will be curtailed.

Summary

Fine particulate matter and ozone have the greatest impact on human health. At levels prevailing in Virginia, they are responsible for increased morbidity and mortality. The death rate from air pollution is approximately 40% of that for tobacco use. The health costs are approximately \$4.8 billion (1.6% of Virginia's gross domestic product).

Interventions that reduce air pollution are accompanied by a comparable percentage fall in respiratory illness in children, and a substantial decrease in death rate. A one-third reduction of air pollution in Virginia could lower children's respiratory illnesses by approximately one-third, reduce death rate by 3% and save Virginia 1.6 billion dollars per year.

Recommendations

Use Energy Efficiently

Home: Insulate. Adjust thermostats for less cooling in summer and less heating in winter. Conserve water and use hot water judiciously.

Architecture: Build environmentally compatible residential and commercial buildings.

Energy supply: Utilize renewable sources (solar, wind, geothermal, etc.).

On-road vehicles: Maintain proper tire inflation. Keep engine tuned. Minimize unnecessary idling (idling engines pollute excessively). Drive within the speed limits (fuel consumption increases drastically above 65 mph). Avoid excessive acceleration and braking.

Enact Legislation

Off-road vehicles: Develop and enact emissions standards for off-road vehicles that parallel standards for on-road vehicles.

Control idling and speed limits: Excessive idling and speeding waste fuel. Banning idling and putting in place lower speed limits would signal the public that energy efficiency is an important component of environmental health.

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